AN ANALYSIS OF SATELLITES AS THE SOLE SOURCE PRECISION APPROACH SYSTEM

GRADUATE RESEARCH PROJECT

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Timothy J. Quinn

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ABSTRACT

Over the last several decades the tremendous growth in the amount of worldwide air traffic has also brought increasing congestion in the skies. Airspace utilization, particularly in the terminal areas, is reaching the saturation point and threatens our ability to safely separate aircraft. Air Traffic Control agencies are attempting to shape policies to alleviate air traffic volume problems in terminal areas using new satellite technologies. As an active player in the world-wide air transportation business, the Air Mobility Command (AMC) is a significant stakeholder in the employment of new technologies for precision approaches.

This paper examines the current and future environment for the use of satellites, particularly the Global Positioning System (GPS), as a stand-alone method of precision approaches. In addition to examining the regulatory and policy environment for satellites, this paper examines the precision approach environments from three perspectives: the Continental United States (CONUS), the European continent, and the Department of Defense (DOD). Each of these perspectives presents unique obstacles to overcome before satellites are employed as the sole use for precision approaches.

Finally, three conclusions are offered regarding the transition to satellites for the precision approach system of the 21st century. First, a truly single source global satellite system (e.g. GPS) probably will never exist, but rather, there will be a combination from various governments and agencies. Second, satellite users, including the DOD, should consider using systems capable of interrogating signals from more than one satellite source. Finally, air traffic control agencies should maintain a network of backup

precision approach systems until the success of a stand-alone satellite system can be confirmed.

AN ANALYSIS OF SATELLITES AS

THE SOLE SOURCE PRECISION APPROACH SYSTEM

I. INTRODUCTION

The tremendous growth in air traffic presents colossal challenges to the air traffic control agencies, air carriers and the military. In recent years, the number of aircraft operations in the U.S. air traffic system has increased at an annual rate of 7 percent (U.S. Bureau of Census, 1997). However, the system infrastructure has been basically made up the same type equipment during the same time period.

As the aviation community worldwide struggles to cope with significant growth, they are also attempting to employ new technologies to ensure a system that is safe, reliable, standardized, and capable of successfully taking the industry well into the next century. Because the Air Force and Air Mobility Command are significant stakeholders in this modernization process, their participation will be critical in the adoption of new technologies in the air traffic system. AMC's adoption of these new technologies is necessary to ensure unfettered accomplishment of the air mobility mission whether in the Continental United States (CONUS), in an overseas theater, or at a forward deployed location.

Problem Statement

The air traffic management system is hampered with aging equipment that may soon be unable to accommodate the constantly increasing demands placed upon it.

However, even conceding the rising fiscal cost of establishing a satellite-based system for precision approaches, costs incurred by delaying the transition to such a system must also be considered. Flight delays, due to system breakdown costs major airlines several billion dollars annually. Furthermore, the more crowded skies led to 225 near misses in 1997, up 22% from 1996 (Oberdieck, 1998).

New satellite technologies that are coming on line must be exploited to ensure appropriate traffic separation, user performance and safety. This is particularly true in the area of precision approaches. A single satellite navigation system will also serve for enroute navigation as well as precision approaches. Such a precision approach system could accommodate increased air traffic and allow for reduced air traffic separation and provide for very precise approaches at any airfield worldwide. This could provide the backbone to instrument flying of the 21st century.

However, there are a number of technical, funding and political questions that must be addressed before such a system could be employed for the precision approaches worldwide.

Research Question

Incorporating the Global Positioning System (GPS) into approach procedures would be a massive undertaking and would require a cooperative effort among numerous agencies worldwide. This paper will discuss the Federal Aviation Administration (FAA) effort to build and certify an augmented version of DOD's GPS for precision approaches in the CONUS and efforts to bring such a system online for other areas of the world to include theater and forward-deployed areas. Additionally, the risks of integrating all

phases of flight into a single GPS-based system will be summarized. The following questions are studied:

1. What is the current state of the FAA's effort to transition from radio-based navigational aids to satellite based navigational aids for precision approaches.
2. What is the status of a satellite-based system in the European airspace?
3. What are the DOD perspectives in the effort to incorporate GPS as a sole means for precision approaches?
4. What are some technical and funding obstacles to employing a single satellite-based system that covers not only precision approaches but also all phases of flight?

Background

The FAA is embarking on an ambitious plan to transition from radio-based to satellite-based navigational aids for precision approaches as well as enroute and non-precision phases of flight. AMC has already begun introducing GPS capability into its weapons systems with the C-17 incorporating GPS into its standard cockpit avionics package. Most other aircrews have some experience with GPS capabilities through hand-held receivers or "add-on" units in the cockpit. Most of the use of GPS to date has been as a supplemental positioning source for enroute navigation. This initial aircrew experience will also prove useful during the phasing in of GPS for precision approaches.

Scope

Overall, this paper concentrates on the transition to satellite signals as the primary method for precision approaches in the 21st century. The use of satellites in the air traffic system of the 21st century will include enroute navigation, communication and air traffic separation. Although the use of satellites for these functions will be mentioned where appropriate, the focus of this paper will be on the transition to satellite signals for precision approach and landing phases of flight. The scope of this paper will include three main areas of research: The FAA's plan to transition from radio-based to satellite-based navigational aids for all phases of flight including precision approach, the international environment for transition to a satellite-based system, and the Air Force role (to include AMC in particular) in the transition effort to satellite based precision approaches and finally, a summary of funding and technical pitfalls of this system.

II. THE CONUS ENVIRONMENT

The requirement of air transportation has grown substantially in North America and Europe. Because Air Mobility Command must share the airspace and, very often, the runways and ground facilities with the commercial sector, the explosive growth in the civil aviation industry will have a direct impact on the command to complete its mission. This is particularly true in all areas of commercial and military aviation including the most crowded airspace (the terminal areas near major airfields). In order to function in the more crowded future environment, new satellite technologies seem to be the technology of choice. As the most developed functioning satellite navigation system, the Global Positioning System (GPS) is usually the centerpiece of any discussion of satellite navigation aids within the U.S.

The Rand Study

With the likelihood of a DOD asset playing a major role in the U.S. civil aviation system, the White House Office of Science and Technology Policy in 1995 asked RAND's Critical Technologies Institute (CTI) to examine the major policy issues surrounding the future use of GPS. The White House also asked for recommended solutions for addressing the future utility of this system (Rand, 1996). The FAA, in its Satellite Navigation Program Master Plan for FY 1995-2000 specified in its Statement of Need: "Satellite navigation potential and opportunities have prompted the aviation industry to begin producing satellite navigation receivers, and aviation users are demanding operational guidance for their use" (FAA SatNav Master Plan, 2).

The Rand study concluded that there was a lack of a clear policy directive from the U.S. government. The study recommended that the government articulate a directive to provide a framework for the various stakeholders---military, commercial and international--in GPS applications. The study went on to indicate that this framework should reassure all users that GPS will continue to operate in a stable, reliable manner and provide civilian signals free of direct charges (Rand, 1996).

While the U.S. bore the burden of funding the deployment and maintenance of GPS, the report indicated that the U.S. also had "an important opportunity to shape the direction of GPS applications and mitigate the risks of this new technology" (Rand, 1996). The policy recommendations were divided into three categories: Integrating Economic and National Security Objectives; Governance and Funding; and Foreign Policy; each with their own costs and stakeholders.

In the category of Integrating Economic and National Security Objectives, the study recommended that the U.S. issue a policy statement on GPS to provide a more stable framework for public and private sector decision-making. They recommended that this policy statement identify U.S. interests and objectives with respect to GPS, address GPS management and acquisition issues, and provide guidance for the development of GPS augmentations and future international agreements. Additionally they recommended that the U.S. initiate discussions with major allies (Japan and Europe) on regional security and economic issues associated with GPS and emerge with mutually beneficial agreements. The study also recommended that the DOD should develop and field anti-jam receivers and antenna enhancements, and to develop electronic countermeasures to selectively deny GPS signals to an adversary. Finally, in the area of

Economic and National Security objectives, the study indicated that the U.S. should not deter private ground augmentation services except for reasons of national security and public safety.

The second policy category addressed by the Rand study was that of Governance and Funding. There are substantial efforts on the part of other national governments and the private sector to augment GPS services. Here, the study endorsed continued U.S. government funding of its space and control segment in order to ensure the stability of the GPS environment. The study indicated that international governance of wide-area augmentations would not harm U.S. security interests and would enhance the international acceptance of GPS.

Finally, in the area of foreign policy, the Rand corporation recommended that the U.S. work to minimize international barriers to commercial GPS-related goods and services. In a note of caution, however, the study recommended that the U.S. should refrain, and encourage others to refrain, from providing wide-area augmentations of GPS (i.e. Differential GPS) until appropriate mechanisms and safeguards are in place (military countermeasures or diplomatic agreements) to deal with potential misuse of the system. The study summed up the risks in the international arena with the following concluding paragraph:

> Failure to reassure foreign governments poses risks for continued U.S. preeminence in GPS goods and services. The international environment for GPS can evolve in various directions, depending on the nature of the U.S. policy. If the United States actively promotes GPS as a global standard, then it will need to address the dual-use nature of the technology through international agreements. If the United States does not actively support GPS or becomes an unreliable steward, GPS augmentations will move forward independent of U.S. interests which, in turn, will encourage the entry of foreign alternatives to GPS. The United States would still have GPS for its own national security purposes, but

> would risk losing the economic and diplomatic benefits from its pasts investments in GPS. (Rand, 1996)

The Rand study strongly emphasized the need for continued U.S. leadership in this area. It indicated that the benefits of "pulling back" (losing preeminence in a dynamically developing industry) on GPS efforts because of isolationist sentiment, are insignificant when compared to the benefits of international preeminence in this leading edge technology and the economic benefit for the American electronics industry. According to the GPS Industry Council, sales of commercial GPS equipment in the year 2000 are expected to grow to about $8.5 billion.

As airspace saturation becomes an increasing concern, governments and regulatory bodies recognize the need for highly accurate aircraft navigation and positioning. Recently, the United States federal government weighed in on this effort. This support was demonstrated on March 29, 1996 when the long awaited GPS Presidential Decision Directive was announced. The directive had three mains thrusts:

1. The Department of Defense will continue to operate, maintain and provide basic GPS signals worldwide, free of direct user fees.

2. The U.S. will advocate the acceptance of GPS and it's augmentations as a standard for use by initiating international discussions and agreement with Japan and Europe.

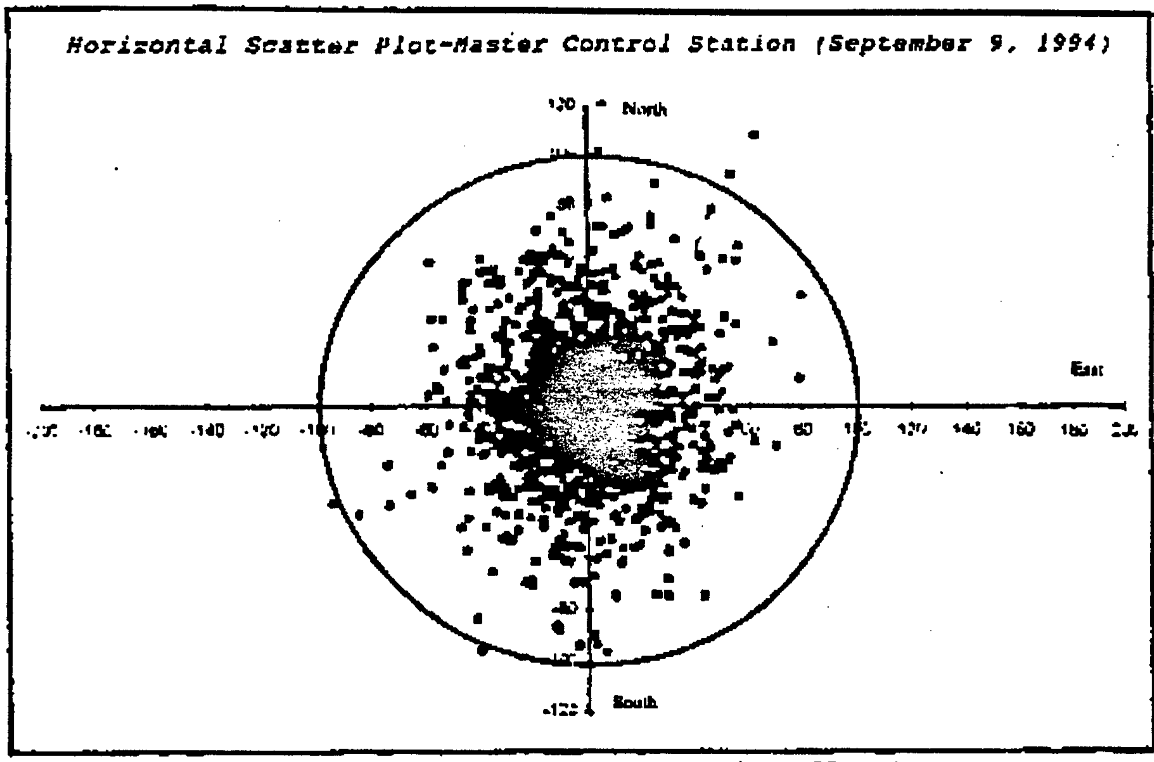
3. The Pentagon, within the next decade will look at ending its practice of degrading the quality of GPS signal available. (President Opens Door, 1996)

The GPS Signals

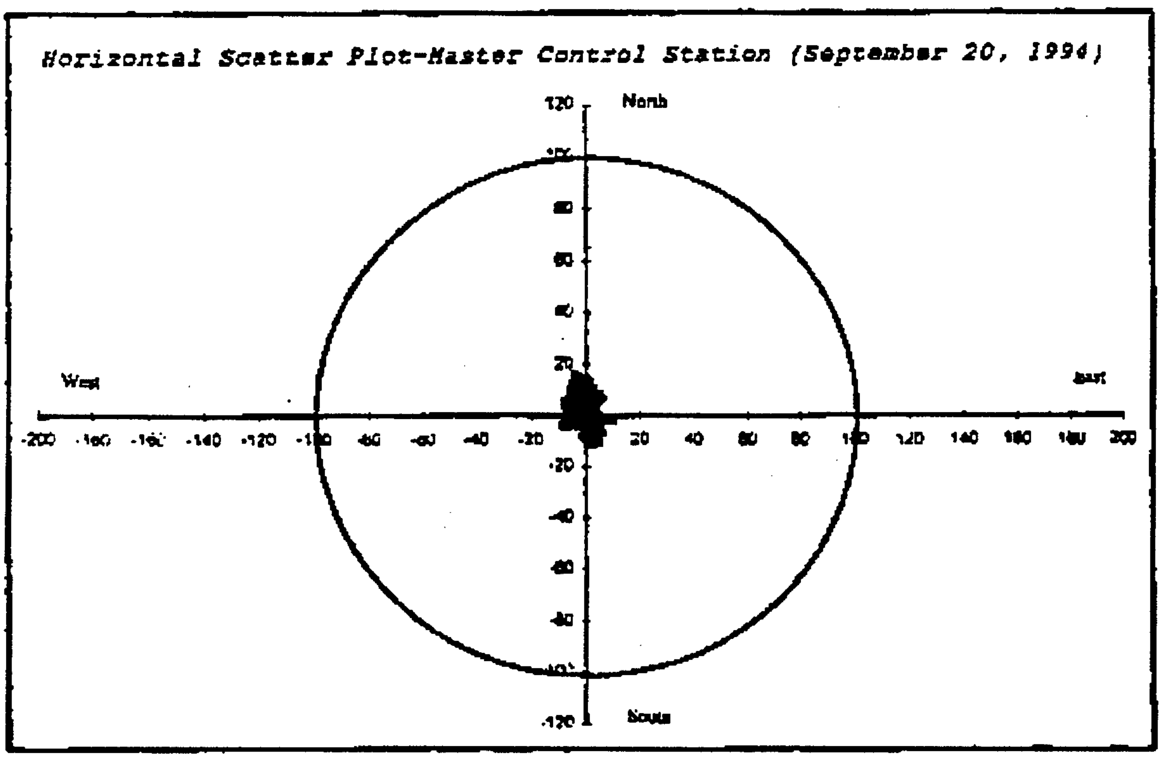
The GPS system was designed to provide two levels of service: a precise positioning signal (PPS) and a standard positioning signal (SPS). The original intent was to make the more accurate PPS available only to authorized users within the DOD. These signals are accurate to within 10 meters. The SPS provides a lower level of accuracy; 100 meters approximately 95% of the time (FAA GPS Transition Plan, p 1-2). The denial of the more accurate signals to the unauthorized user is known as selective availability (SA). SA was instituted to protect against adversaries who could use signals for their own navigation purposes.

Figure 1 on the following page illustrates the difference in the accuracy of the two signals. The two plots are data points based on snapshot postions taken one minute apart over an entire day. The upper graph represents the resulting data with SA turned on. With the degraded signal, nearly all of the signals fell within the 100 meter arc. However, another collection of data points taken 11 days later with SA turned off and the results are easily understood. Although the same number of observations were taken, they are tightly grouped near the center of the target.

In 1996, President Clinton announced that the practice of SA will end by 2006. This plan also calls for a system that can eliminate service in specific geographical areas as needed in the event of war within a particular theater (Wald, 1998). With the United States' intention to eliminate selective availability, a multitude of benefits is realized to the aviation community at large. These benefits include improved stand-alone



Horizontal Scatter Distribution (SA on)



Horizontal Scatter Distribution (SA off)

Figure 1. Accuracy Comparison SA on / SA off (National Research Council, 1995)

navigation, positioning and timing accuracy, approved availability for any given positioning accuracy and further systems modifications to improve the accuracy of satellite navigation systems. Ironically, this move to allow the free use of the DOD's more accurate signal worldwide could also bring about problems for the military aviator. Civil aviation authorities, both international and domestic, are aggressively moving toward satellite-based precision approach systems. This will require the military aviation community to follow the lead of the civil sector in order to be assured of unrestricted use of approach and landing systems.

GPS Augmentation Efforts

GPS signals in navigation initially emphasized in the high altitude and oceanic environment. The advertised accuracy of the less precise SPS (100 meters) was sufficient to use the system as a supplemental or primary method of navigation in the oceanic environment. Because most of the oceanic airspace is well outside the range of conventional radio navigation aids, GPS was a welcome source of navigational information. In 1994, GPS signals were approved by the International Civil Aviation Organization as a primary means of navigation in the oceanic environment (FAA, 4).

However, as seen in Table 1 below, the accuracy, integrity, time to alarm and continuity standards for GPS signals during Category I precision approaches (to within 200 feet above the runway) is substantially greater than the requirements for the enroute through non-precision approach phases of flight.

Table 1. Navigation and Category I Landing Guidance Performance Requirements (FAA Global Positioning System Transition Plan, 1997)

	Enroute Through Non-Precision Approach	Precision Approach CAT I
Availability	0.99999	.999
Accuracy (95%) Horizontal Vertical	 100 m Not Specified	 7.6 m 7.6 m
Integrity Probability of HMI*	10^{-7}/hour	4×10^{-8}/ approach
Time to Alarm	8 sec	5.2 sec
Continuity	$1 - 10^{-8}$/ hour	.99995 / approach

* Hazardously Misleading Information

"Availability" from Table 1 above represents the probability that at anytime the system will meet the accuracy and integrity requirements for a specific phase of flight. "Accuracy" is the degree of conformance of an aircraft's measured position with its true position. The "integrity" requirement is expressed as a probability of the system providing hazardously misleading information (HMI) for a particular phase of flight with "time to alarm" an HMI condition expressed in seconds.

While basic GPS signals are suitable for many phases of flight, the requirements of the precision approach exceed the capabilities of the stand-alone system. Basic GPS (SA off) meets the accuracy requirements for en route through non-precision approach but not for precision approach. To meet the stricter precision approach requirements the FAA is undertaking two programs to augment GPS signals: the Wide Area Augmentation System (WAAS) and the Local Area Augmentation System (LAAS). Both systems are based on the Differential GPS (DGPS) concept where existing GPS signals are monitored

and correction factors computed and relayed to users that are also interrogating the same GPS satellites (The GPS: A Shared National Asset, 1995).

The FAA is pursuing WAAS to provide an improved signal for enroute travel, non-precision approach and CAT I precision approach capability for the United States and some outlying areas (FAA, WAAS index homepage). The system is based on a network of approximately 35 ground reference stations. This equipment is designed to interrogate GPS satellites and compare the GPS-derived position with their known locations and determine the positioning errors for each GPS satellite. These differential correction factors are then relayed to aircraft via geostationary communications satellites. Because the WAAS signal will be transmitted on the same frequency and with the same type of code-division multiplex modulation as the GPS signal, receivers will be able to acquire both GPS and WAAS broadcasts. In addition to the correction signals, the geostationary satellites will also serve as additional sources of GPS ranging signals thereby increasing the number of satellites available to the system's users.

The accuracy provided by the WAAS will support precision approaches to CAT I minimums (the least restrictive) but not to CAT II/III minimums. The more stringent minimums of CAT II/III will require a LAAS. Under this concept, the corrections to GPS are broadcast to aircraft within line of sight to an airfield. This service, therefore, will typically be limited to 25 to 30 nautical miles (FAA GPS Transition Plan, p2-5).

Research indicates that development of the LAAS is somewhat behind that of the WAAS. Currently, the FAA is pursuing requirements and system specifications with initial acquisition of LAAS equipment in the year 2003 at the earliest with full operational capability expected in the year 2006 (Swider, FAA).

Phaseout Of The Instrument Landing System

The Instrument Landing System (ILS) is currently the worldwide standard for precision approach and landing. Because of operational and technical limitations of the ILS, a Microwave Landing System (MLS) was developed in the 1970s as a replacement for the ILS. The FAA worked toward an original commitment to have MLS systems installed on all international runways within the United States by January 1, 1998. Because of the significant progress of satellite aided approach studies, it became clear that MLS would become an interim solution bridging the gap between ILS and a satellite-based approach infrastructure. The General Accounting Office (GAO) weighed in on the issue by calling the FAA's decision to replace ILS with MLS as "premature." Furthermore, "MLS benefits and capabilities may be provided by alternative systems such as ILS-enhanced with a computer-based flight management system on board aircraft and GNSS" (Lopez, 19). With the issue now simply whether MLS was cost-effective as an interim solution, the future of this system in the United States was questionable. Additionally, after numerous delays, improvements in existing ILS systems and the primary winner of the MLS competition going bankrupt, much of the wind has been taken out of the MLS sails (Schanzer, 1995). The United States recommended at the ICAO Communications/Operations Divisional meeting in the spring of 1995 that the mandatory transition to MLS by 1998 be repealed and that ILS be retained as an alternate until satellite-based precision landing technology could be fully evaluated. This recommendation was adopted ensuring the continuation of the ILS for several years. However, the MLS still has a role in certain environments to be discussed later in this paper.

Because it is fiscally unrealistic to maintain a dual precision approach capability at every runway, the FAA has established a phase-out strategy for the ILS with decommissioning of this system to begin in 2005 and to be complete by the year 2010. This strategy provides a 10 year transition period as the move to the GPS/WAAS/LAAS is completed. By the year 2005, it will be assumed that most IFR aircraft are at least single-GPS/WAAS equipped, and Category I ILS's will begin to be decommissioned. By 2010, the remaining ILS systems will "be rapidly phased out" (FAA GPS Transition Plan, 1997). Figure 2 below indicates the FAA's timeline for the strategy for the phase-in/phase out of precision approach systems. As the figure below indicates, by the year 2005 traditional ILS precision approaches will begin to disappear from CONUS architecture.

The FAA is aggressively pursuing the transition to a satellite-based approach system for a variety of reasons. Its GPS Transition Plan highlights benefits for both the users and the FAA. For the aircraft operators, the benefits include increased operational efficiency and safety and reduced equipment, maintenance and training costs. The FAA asserts that because there will only be onboard equipment for only one landing system to maintain in the aircraft (rather than the multiple systems which exist today) the savings will be substantial.

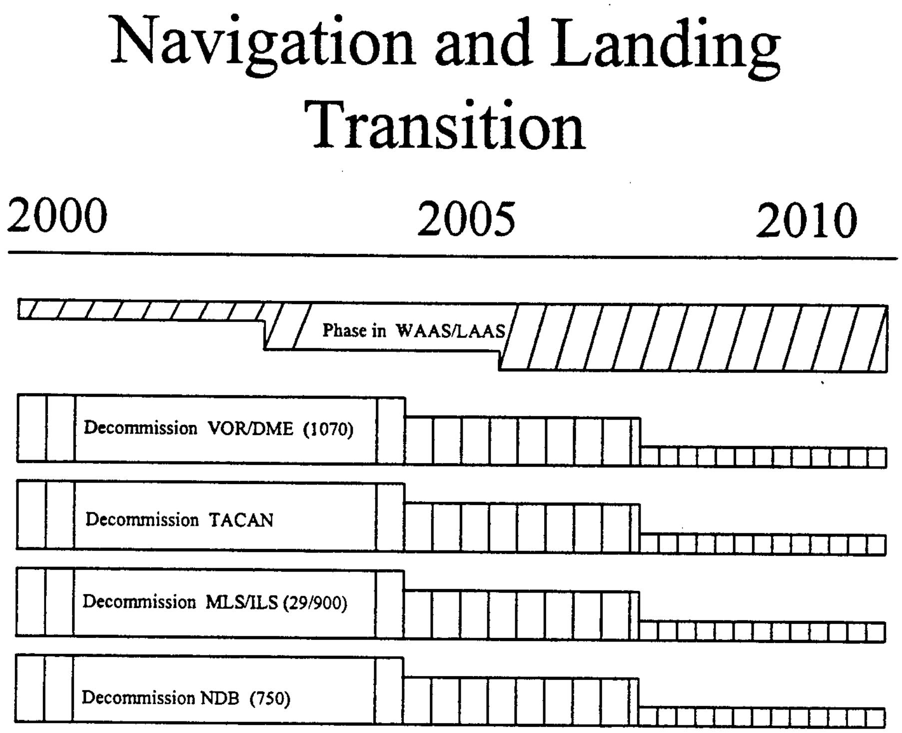


Figure 2. FAA Phase-Out Targets (Institute of Navigation)

For the FAA, the primary benefits come from eliminating the sustainment costs of the existing ground-based navigation and landing guidance systems, which total approximately $200 million per year just for operations and maintenance. Once fully established, the FAA projects an O&M cost of about $80 million per year for WAAS and LAAS. The FAA intends to maintain both the ground-based landing system and the satellite system during the 10-year period prior to decommissioning of the conventional navigation aids (FAA GPS Transition Plan, 1998).

However, there is significant debate in the aviation community for maintaining traditional navigation and approach equipment as a backup to the satellite system well

beyond the year 2010. Some experts have raised concern that completely phasing out traditional navigation aids will take away an important backup source to GPS signals. FAA concerns about deliberate or natural interference with GPS radio-navigation signals are causing the FAA to rethink whether GPS is suitable as a sole means of navigation. Experts are considering the use of LORAN (Long Range Air Navigation), VOR-DME (VHF Omnidirectional Range-Distance Measuring Equipment) and traditional ILS systems to back up the satellite system for enroute navigation and precision approach signals (Anser Corp: 91: 1998). This sentiment was echoed by the President's Commission on Critical Infrastructure Protection. A recently released report raised concern about the wisdom of the intended policy to use GPS as the sole source of navigation (to include precision approaches) and called for the study of maintaining traditional navigation aids as a backup to avoid over-reliance on one single system (President's Commission, 1997).

III. THE EUROPEAN ENVIRONMENT

Overview

According to a recent article in Janes's Airport Review article "nothing divides the world's ATC regulatory bodies quite as much as the issue of next-generation landing aids" (Butterworth-Hayes, 1994). The International Civil Aviation Authority (ICAO) exists to ensure implementation of an air traffic system in a standardized format. Over the last few decades, the world has indeed "gotten smaller" in terms of international communication and travel. New technologies rarely respect political boundaries and the use of satellites for precision approaches is no exception.

Since the Korean Airlines 007 shootdown on September 1, 1983 the United States declared a policy of free worldwide availability of its GPS signals. Although it would initially seem that the GPS option would be attractive to the Europeans, they appear to be the most reluctant region to accept GPS as the backbone of any precision approach system. This reluctance comes despite the American offer to provide navigational signals, free of charge, to users everywhere to prevent another tragedy due to navigational error.

European Political Concerns

While this announcement provided the U.S. an opportunity to take the role of benevolent benefactor to the world, many in the European community regarded this announcement with a degree of suspicion for three reasons. First, the acceptance of the system for precision approaches would provide an economic stimulus for the growing and

American-dominated GPS industry. Second, American technological preeminence is an indispensable element of international political influence. Finally, reliance on the DOD-provided satellite system will enhance U.S. security in that it would slow the development of alternative satellite radio-navigation systems which would serve to reduce potential military threats as well as commercial competition (Charting the Future, 1995).

The heart of European misgivings is that the U.S. would have the ability to hold their precision approach system hostage to their own interest. One European official, speaking at the Annual Air Traffic Control Association Conference in 1994 summed up the situation and a possible alternative from the European perspective.

> European fears about relying on a U.S. DOD system for civil navigation have not been extinguished. The overriding legal and institutional problems associated with the provision of a global facility by a single state monopoly provider should not be underestimated. Indeed there are many in Europe who insist that these issue can only be resolved with the creation of a purpose-built satellite system designed and operated for civil aviation. (Wilson, 1994)

Over European protests, the U.S. convinced the ICAO in 1995 to drop MLS as the successor to ILS in precision approaches worldwide. This move placed the GPS in the driver's seat to became the medium for the approach aid for the 21st century. However, part of the European problem was the nations were not unified in their preferences in precision approach systems.

The United Kingdom's concern, for example, was that commercialized air traffic control authority sold ILS localizer frequencies to commercial radio stations (Schanzer, 1995). Because of their problem with ILS frequency availability, the U.K. required a replacement for the ILS sooner than its partners in the European Community or the U.S.

Therefore, they felt compelled to pursue MLS more aggressively than other European nations. Despite the ICAO's move to discontinue the MLS transition, the British are continuing to develop systems to accommodate both MLS and GPS. The Royal Air Force, a major stakeholder in the U.K. precision approach structure anticipates additional guidance and an MLS Implementation timeline when their Strategic Defense Review (SDR) is published sometime this year (Kennish, 1998).

European Options

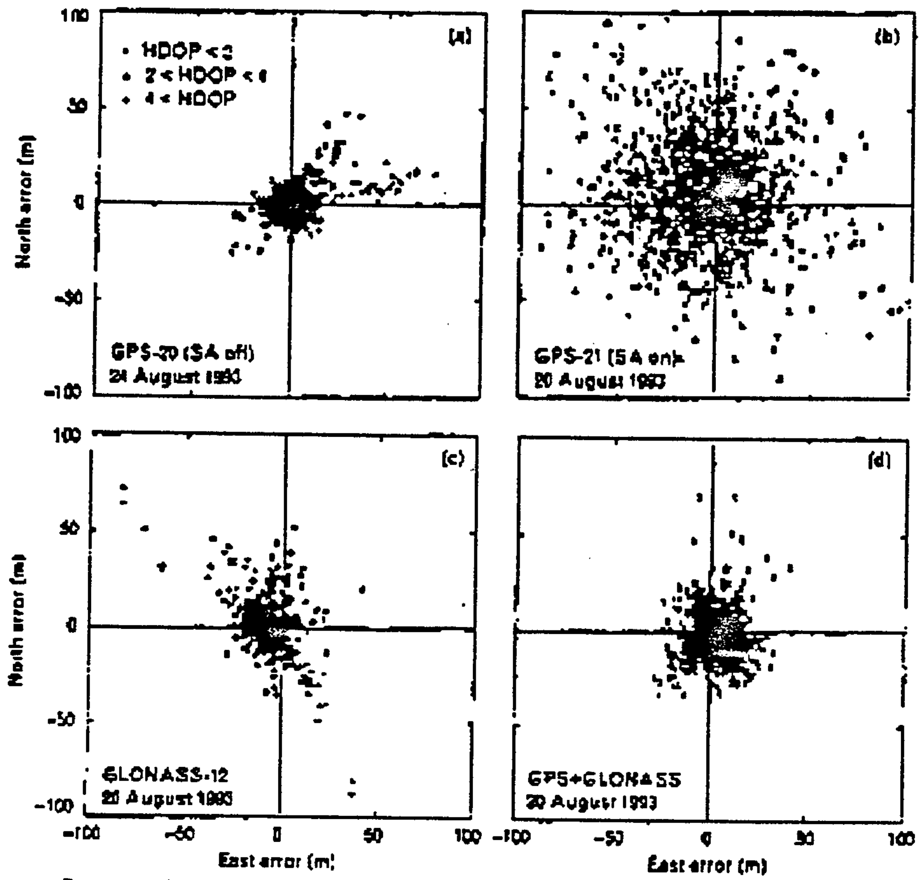
In the wake of the ICAO decision, the European community is considering several options and is conducting ongoing studies with GPS technology with the possibility of incorporating these signals throughout the continent's infrastructure. European experiments with DGPS landing signals were deemed successful enough to continue these efforts (Flug Review, 1). However, it is unlikely that Europe will pursue GPS alone as the only source for precision approach.

Another option is to diversify their signal sources by incorporating the Russian Global Navigation Satellite System (GLONASS). Similar to the GPS, this system consists of 24 satellites deployed in 3 orbital planes (GPS satellites utilize 6 planes). Unlike GPS, GLONASS has disavowed any plans to degrade the signals available for civil use (MIT Lincoln Laboratory, 1) However, the system separates its signals into two levels of service. The Channel of Standard Accuracy (CSA), available to all civil users, shall provide horizontal accuracy of 60 meters with 0.997 probability, and vertical position accuracy of 75 meters with 0.997 probability. The Channel of High Accuracy (CHA) shall be available only to authorized users.

One drawback to the GLONASS system, from the European perspective, is its uncertain viability. Substantial European assistance would be required to field a viable system to meet the needs of the European aviation community. As of early February, 1998, the financially strapped Russian Federation has not launched replenishment satellites for about two years. While the GLONASS calls for a constellation of 24 satellites, the number of known healthy satellites has fallen to 15. Furthermore, no date of completion has been set.

The CSA signals from GLONASS, though not degraded, do not meet the required accuracy requirement for precision approaches. However, experiments that combine the CSA signals and SA signals from GPS reveal interesting results. As figure 3 below indicates, the accuracy advantage when interrogating signals from both GPS and GLONASS is substantial. The graph in the lower right, which combines positioning data while interrogating the standard civil level signals from the GPS and GLONASS systems indicates a respectable positioning accuracy about equal to the level of the DOD-reserved signal as indicated in the graph at the upper right.

As an additional benefit of combining the system, the combined GPS and GLONASS systems boast a constellation of 40 fully functioning satellites. This would virtually guarantee no gaps in satellite coverage for receivers capable of interrogating either type of signal. For their part, the Russian position is that they will cooperate with international organizations to make GLONASS signals available for civil aviation (Ministry of Defence, GLONASS Homepage).



Courtesy of MIT Lincoln Laboratory

Figure 3. Accuracy Advantage of Combined Signals (NRC, 1995)

Europe also enjoys a unique historical geographic advantage when combining the two systems. When each of the systems were conceived and initially deployed, the Cold War dominated international politics. Because both the U.S. and the former Soviet Union believed Europe to be a likely future battlefield, satellite coverage over the continent is better than any other location in the world, including the home countries of each of the sponsors.

As the Europeans ponder their options, they are pursuing a concept known as the European Geostationary Navigation Overlay Service (EGNOS). This program started as an initiative of the European Union (EU) together with Eurocontrol and the European Space Agency (ESA). This system is designed to make GPS and GLONASS signals more accurate. While interrogating signals from the two military satellite systems the concept calls for correction signals to be broadcast via Inmarsat III mobile communications satellites. Further out on the horizon are plans that include a non-military global system for civil use. Three options considered by the EU include: joint development with the U.S. and all other major nations, EU cooperation with one or more specific international partners, or a "go-it-alone" plan of an independent EU system (ION, 1997). Although estimates vary, some sources talk of a new civil satellite system built, launched and dedicated primarily to European aviation uses that would also accommodate precision approaches that would cost 1-2 billion ECU (approximately 2.2 billion US dollars) to deploy. This figure is substantial, but feasible (Schanzer, 1995).

Another obvious incentive for European involvement in the satellite market is economic. Neil Kinnock, U.K. Parliamentary Space Committee offered this analysis: "When reasonable estimates suggest that the world market could be worth 50 billion dollars within seven years, the European strategy must obviously be to put our countries in a position to capture some of this market (ION Newsletter, 1998).

Because of commercial and military ties to the region, the U.S. has much at stake in the European decision. The U.K.'s dual pursuit of MLS and satellite precision approaches may have an impact on American civil and military aircraft. For example, few U.S. military aircraft are equipped with MLS avionics and would be limited to the

Precision Approach Radar (PAR) if ILS were decommissioned in favor of the MLS. Some of these issues are expected to be addressed in the Strategic Defense Review, due out sometime in 1998.

Because of extensive operations in European airspace, the U.S. aviation community, civil and military could be significantly affected by the European decision for the next century's precision approach strategy. If the European community decides to certify precision approaches based on the interrogation of a combination of satellite signals (GPS, GLONASS and some form of civil GNSS) then it is also likely that all users of their system will also be required to interrogate the same systems in order to accomplish precision approaches in their airspace. Although DOD has no plans to equip its aircraft with receivers capable of interrogating both systems, there are currently commercially available receivers that can interrogate GPS and GLONASS signals. In his article "Satellite Navigation for Precision Approach: Technological and Political Benefits and Risks," Gunther Schanzer from the Institute of Flight Guidance and Control, proposes a European owned and operated satellite system to provide precision approach signals without the risk of a military organization removing the service in the name of national security.

IV. DOD PERSPECTIVES

Overview

As a major stakeholder in the precision approach system of the 21st century, the DOD recognizes the importance of keeping pace with the civil aviation community on the use of satellites for navigation and precision approach purposes. While the airlines are primarily concerned with precision approach systems in the developed areas, the Air Force and AMC in particular, must be prepared to fly into the third world areas as well. To have a single system capable of serving the needs of both arenas would be sound.

Global Air Traffic Management

Within the next decade, issues complicated by problems of politics, security and technology will require continued upgrades in state-of-the-art avionics for IFR aircraft in order to be assured unrestricted use of airspace worldwide. The DOD concept for the necessary modifications for the future airspace infrastructure (to eventually include satellite-based precision approach capability) is called Global Air Traffic Management (GATM). Throughout all discussion of the future environment of air traffic control, the overall theme is the more efficient use of airspace and the use of advanced technology to accomplish this safely

The importance of satellite technology is addressed in the "Air Force Doctrine Document 1." Referring to the capabilities of the GPS, the doctrine indicates that "navigation and positioning are key elements of information superiority and global awareness (Air Force Basic Doctrine, 60). The DOD's immediate motivation to

incorporate GPS avionics into all its aircraft satellites is not only for precision approaches, but rather, a host of air traffic control issues.

Although this document focuses on the application of satellite technology for precision approaches, the initial focus of GATM is for DOD aircraft to function in the high level, enroute environment, especially in the oceanic areas. In the "Capstone Requirements Document," the DOD refers to the current and future air traffic environment requiring "significant upgrades in order to increase flight efficiency and system capacity while continuing to meet flight safety standards. (Capstone Requirements Document, 1). Because the United States Defense Planning Guidance (DPG) requires US military forces to be highly mobile and capable of rapid response to a wide range of military options anywhere in the world, the DOD will ensure that its aircraft will not be "technologically challenged" in the coming years. In order to effectively deter aggression, conduct humanitarian relief operations or project the forces in support of American national interest, the DOD must preserve access to prime global routes by equipping aircraft to meet the requirements of the future aviation environment (Capstone Requirements Document, 2).

The Air Mobility Master Plan (AMMP) outlines the importance of satellite usage into the next century. In line with the GATM concept, the immediate focus is on the use of satellites for high-level enroute navigation to preserve access to the most desirable routes in oceanic airspace. The AMMP acknowledges that the world civil aviation community is rapidly upgrading its technological tools via the GPS, digital data communications and advanced automation in oceanic airspace.

> As the increased capabilities of the newer systems are integrated into normal operations, civil aviation authorities will increasingly restrict aircraft that do not meet the new standards. Our mobility fleet requires avionics upgrades to preserve unrestricted access to prime global routes into the 21st century. (AMMP, 1997)

Using a principle known as Required Navigational Performance (RNP) In December 1994, the ICAO certified GPS as a primary means of navigation for oceanic operations. Due to an increasingly crowded airspace over the North Atlantic, the ICAO is also working to reduce the separation standards in order to allow more aircraft into the same amount of airspace. The first step of this program is RVSM (Reduced Vertical Separation Minima). Enacted in March of 1997 it reduced the vertical separation between aircraft in oceanic airspace from 2000 feet to 1000 feet (Pulse, 1997). By the year 2003, the ICAO will further subdivide the airspace by reducing the lateral separation to 30 miles.. In order to safely subdivide the airspace, ICAO also plans to establish RNP-4 standards and reserve the most desired altitudes (above FL 290) for aircraft that meet Required Navigational Performance (RNP) Standards. RNP means that an aircraft must be within the specified accuracy standards for 95 percent of its inflight time. For instance, the RNP-4 standard (mandating that aircraft remain within 4 miles of their courseline 95% of the time) is expected to be in place in the North Atlantic Airspace by the year 2003. Those aircraft that do not meet the RNP requirements will be denied the most desirable routes and altitudes.

Failure to comply with the stricter RNP requirements would deny AMC aircraft of the most desirable routes and altitudes. This restriction would greatly impact the command's global capability, making non-compliance unacceptable. The cost in time and fuel is prohibitive for the DOD not to ensure full compliance with RNP standards. In

future years, the RNP standards will eventually be reduced to RNP-1 for oceanic airspace worldwide. Because of the absence of radio navigational aids in oceanic environment, and with most oceanic airspace out of range of conventional radar, other satellite-based equipment is needed on board aircraft to meet the Required Navigational Performance standards.

In his address to the 1997 Airlift Tanker Association Convention, AMC Commander, General Walter Kross summarized the importance of the GATM effort, his commitment to the new technology necessary in the air traffic environment of tomorrow and the consequences of non-compliance:

> Worldwide increases in the volume of air traffic have resulted in aircraft being required to have more high-tech equipment on board as a prerequisite to flying in some airspace. This spring we entered the era of restricted global reach for the first time when our 600 KC-135s and part of our SAM fleet were closed out of certain altitudes crossing the Atlantic. More restrictions are on the way next Spring in the Pacific. The reactive response would be to watch closely as the worldwide air traffic requirements change, and frantically try to stick this or that piece of equipment on our aircraft so they could continue to fly worldwide. The proactive approach is more complicated, but much more effective. We are now in partnership with the Joint Staff, OSD, FAA, ICAO, and the airline industry to shape GATM requirements. (Kross, 1997)

In its Capstone Requirements Document on Global Air Traffic Management (GATM), the Air Force acknowledges the importance of keeping pace with the new technologies:

> If aircraft are not equipped with the appropriate new technologies, they will not be able to operate safely in airspaces where these new separation standards and air traffic management procedures are implemented by civil authorities, and they may therefore be excluded from those airspaces. (Capstone Requirements Document, 1996)

Additionally, the Quadrennial Defense Review (QDR) added a substantial endorsement to satellite-aided navigation:

> Upgrades to the space-based Global Positioning System and compliance with global air traffic management rules that will be coming into force over the next several years will require significant future expenditures which are get to be determined. The challenge is to efficiently implement upgrades to the positioning satellite constellation and user equipment that allow us to respond effectively in time of crisis and to facilitate our participation in the air traffic control system and other navigation and safety efforts. (QDR, 1997)

Although DOD is aggressively pursuing the incorporation of satellite technology in compliance with GATM requirements, the command's motivation lies in enroute navigation with precision approach capability further out on the horizon. The Air Force Capstone document indicates that compliance with Required Navigation Performance (RNP) standards is "the initial focus of GATM, with a growth path to free flight and precision approach capability. (Capstone, 4).

V. THE DEPLOYED ENVIRONMENT

Overview

Because of the absence of a widely developed precision approach infrastructure, the regions of the Third World appear to be an attractive area to employ GPS satellites for precision approaches. With the recent history of humanitarian airlift efforts into these areas, a new precision approach concept into the third world has become a DOD priority. Unfortunately for a satellite based-system, there is likely not to be a ground-based augmentation system in the foreseeable future in these areas. Therefore, the traditional WAAS and LAAS concepts that are being developed in the U.S. are decades away for the third world. However, if additional satellites are deployed and receivers capable of interrogating GPS, GLONASS and Inmarsat satellites, precision approaches solely from satellite signals could be a possibility.

Precision approach capability is critical to the mission of the Air Force worldwide. This is especially true in the deployed environment. Austere field conditions combined with low-visibility weather can stop or slow a critical contingency anywhere in the world. The recent example of Operation Joint Endeavor in late 1995 demonstrated that the world's major military powers can be slowed or stopped by bad weather. This episode highlighted the importance of precision approach capability for U.S. and Allied aircraft in the event of any contingency (Gravelle, 1997).

A major selling point of using satellites for precision approaches at austere locations is that the state of infrastructure at the local airstrip would be less relevant. In the utopian environment, aircraft should be able to accomplish a precision approach using

satellites on a stand-alone basis. However, testing has shown that satellite signals alone lack the vertical accuracy required even for a CAT I precision approach. As indicated earlier in this document, substantial ground or satellite-based augmentation of satellite signals is required to meet the parameters of a CAT I or better precision approach. The FAA's WAAS/LAAS projects and the European concept of additional satellites to augment existing GPS or GLONASS signals are examples colossal efforts on the national governmental scale to refine signals to precision approach standards. Additionally, extensive certification testing and database refinement would be needed before a satellite precision approach can be instituted at any field. In an undeveloped area, these procedures would require substantial preparatory work before a precision approach could be implemented (Overbey, 1997).

The Mobile Microwave Landing System

Air Force Manual 13-220, "Deployment of Airfield Operations," defines operations, command relationships, training standards and capabilities of airfield operations and Deployable Air Traffic Control and Landing Systems (DATCALS). Current guidance from that manual indicates that a system known as the Mobile Microwave Landing System (MMLS) provides the required signals for aircraft to land at deployed locations using a precision approach.

Although the MLS has been rejected as the precision approach of choice by most of the civil aviation community, it is attractive to the DOD's mobility community for the following reasons. First, unlike the ILS, it can provide curved approach paths and unusual glideslopes to incoming aircraft, a critical feature when the deployed airstrip is

located in mountainous terrain. Second, MLS is more difficult to jam than the low powered GPS signals which helps answer some security concerns. Third, the MMLS is a self- contained unit that can be airdropped from a C-130 and be made operational by a small team of technicians within a few hours. And finally, the MMLS has demonstrated good reliability in operational tests. Currently, the C-17 is being delivered with MLS capability installed. MLS capability is also being installed in most C-130 aircraft, providing this approach capability in the two DOD aircraft most likely to be deployed into the forward areas (Gravelle, 1997).

Other research efforts (beyond the scope of this paper) including the integration of Inertial Navigation Systems (INS), Barometric Altimeter and Radar Altimeters have found the assistance of a ground-based DGPS was required to meet precision approach accuracies (Britton, 1995, xxi). Because of the lack of resources in many of the undeveloped areas of the world, substantial ground augmentations cannot be expected.

Because of the immediate need for precision approach capability and the uncertainty of the time frame for established technology for satellite-based precision approaches in the forward areas, DOD has elected to pursue MLS. General Kross, AMC Commander, has indicated that MLS is the precision approach of choice in the deployed theater until new technologies become available (Kross, 1997).

VI. OBSTACLES TO IMPLEMENTATION

Overview

The concept of going to a completely new structure for navigation and precision approaches is both promising and daunting. The sheer size of the task to implement new procedures on a worldwide basis might be the most significant obstacle since the era of modern air traffic control began. The potential obstacles that may delay the implementation of a system for satellite-based precision approaches are in the areas of funding and system vulnerability.

Funding

A recurring theme with many ambitious and revolutionary technological concept in this arena is that many new promising concepts are derailed when the shortage of funding "rears its ugly head." In the euphoria of their introduction, many of the estimates are low-balled as far as cost estimates go. The use of a GPS-based precision approach is no exception.

A recent Wall Street Journal article summarized the saga of implementing the help of GPS to help reduce the risks of America's increasingly crowded skies. Mr. David Hinson, the FAA chief in 1994 called for the hastened development of a $400 to $500 million network of ground stations that would allow commercial aircraft to rely on DOD signals as navigation and approach aids. "It's phenomenal," he remarked that year. "Once in a while those of us in a specific science are privileged to be around when something introduced is truly revolutionary. We are no longer studying, we are ready to

start building" (Oberdieck, 1998). However, four years after that statement, it appears that the building has barely begun. Cost projections for the system of ground stations have skyrocketed to levels many times Mr. Hinson's original public estimates.

An example of cost overruns plaguing the system could be seen in the expensive false start of the FAA's WAAS effort. The contract was originally with Wilcox Electric for over $400 million. However, after cost overruns, the FAA became convinced that the emerging system "looked unreliable" and that they would be "more comfortable" with a larger company. Due to these concerns the government terminated the contract with Wilcox Electric and issued a new contract to Hughes Electronic for $475 million. Settlement payments to Wilcox Electric included "$42 million in 1995 and 1996 and $18 million more is likely to be paid in 1999" (Oberdieck, 1998).

More pessimistic feedback came at the 1997 Transportation System Acquisition Review Council when the FAA acquisition chief, George Donohue indicated that "the money is going in the opposite of the system." While cost estimates for GPS augmentations are increasing, Congress is squeezing the FAA's capital budget, which fell 22% between fiscal 1992 and 1998 (Oberdieck, 1998).

With some cost estimates for a complete and certified satellite system for precision approaches in the United States topping $50 billion, the $200 million annual cost of continued maintenance and use of the current ILS system seems insignificant.

As with many DOD programs that are caught up in funding constraints, suggestions of privatization have come up. However, the nature of the GPS system would make this move very complex to say the least. The Anser Corporation, in a recent newsletter reported on increasing interest in the privatization of GPS, and the complicated

issue if privatization for this system.

> Privatization of GPS raises questions about what company could compete with a free governmental service and how the military would deny enemy exploitation of a satellite navigation system. As commercial airline companies rely more on GPS for precision navigation and landing, there is a greater interest in a system that offers private companies and foreign countries more control over the system. (Anser Corp., 1998)

Vulnerability

Critics of a satellite-based precision approach system point to the system's vulnerability as its Achilles heal in the future environment. With the satellites settled into 11,000 mile orbits the space assets may be presumed safe from all but the most sophisticated terrorist or enemy nation. However, their signals are extremely low powered and subject to attack from earthbound jamming devices, which exist today. A Russian-made 4-watt jammer went on display at the Moscow Air '97 air show. Said to have the capability to interfere with civil and military frequencies out to a range of 200 nautical miles, the device is reportedly fully functional. The manufacturer reported interested customers in the Middle East (Aviation Week, 1997). The ability for an enemy or terrorist to disrupt navigation signals over a long range casts a satellite system in a very vulnerable light.

GPS and its GLONASS cousin may also be technically vulnerable. While discussing technical concerns, the field experts indicated that concerns about deliberate or natural interference with GPS radio navigation signals are "a major cause for a major change in FAA thinking on GPS as sole means of navigation (Anser Corporation, 1998).

While the deliberate destruction or degradation of an orbiting satellite may not be within the capability of most nations or terrorist groups, there is always potential for

mechanical or electronic failure. The recent failure of the PanAmSat Galaxy IV satellite provided a stark demonstration of the vulnerability of satellite technology and the consequences of failure. When the geosynchronos communications satellite ceased to function and began to roll out of position about 80% to 90% of the U.S. pager traffic was suddenly cut off. News accounts of that event indicated the tremendous repercussions of our dependence on technology, which is so often taken for granted until its failure produces a great impact (Lavoie, 1998).

The consequences of a disruption of a satellite navigation system would also have a great impact on air traffic, both civilian and military. Because any system of this type would be composed of multiple orbiting vehicles, the system may be somewhat insulated from a catastrophic overall failure. However, the possibility of dangerous consequences for an aircraft relying on those signals during a critical portion of flight must be considered.

Another vulnerability of a system of this nature is that the failure or degradation of a satellite system would affect safe navigation for enroute as well as terminal area traffic on final approach to a runway. With different areas of the air traffic system relying on the same signal source, the case could be made that we area setting up a "single point of failure" for the entire air traffic system.

VII. RECOMMENDATIONS AND CONCLUSIONS

Research Paper Summary

Satellites are on the threshold of replacing the traditional navigational aids not only for high level enroute navigation, but also for precision approaches. Because the raw signals alone do not provide the accuracy needed for precision approaches, substantial ground or satellite based augmentation sources will be necessary. The installation of a network of WAAS stations is already in progress in the U.S. and the European Union is considering its options for this concept as well.

The DOD is also keeping pace with the satellite revolution with its GATM concept. Currently, this concept is being employed to ensure its aircraft have access to the most desirable routes and altitudes throughout the world. This is an absolute requirement in order for the DOD to continue to meet its mission commitments. There are plans, however, to employ the same system for precision approaches. However, the current approach aid of choice in the deployed environment is the MLS.

The implementation of a new satellite-based system from precision approaches is a colossal project requiring the cooperation of military and civil organizations around the world. There are significant funding and vulnerability obstacles which are likely to delay, but not necessarily prevent its introduction as the approach aid of choice for the 21st century.

Conclusions

As the new system begins to take hold, my research has led me to the following conclusions:

1. There probably will be no truly global satellite system, but rather signals will come from combined sources to include non-military satellites.
2. The DOD should consider using systems capable of interrogating signals from alternative satellite sources.
3. Maintain a secondary backup system for the foreseeable future.

A "Global System?"

The U.S. and Europe will lead the way to the transition to satellite signals for precision approaches for the next century. Although the U.S. plan is to rely on the DOD-provided signals for its precision approaches, there is reluctance from the other side of the Atlantic to do the same. This reluctance comes despite American promises to make the precise military GPS signals available free and without condition. The European Union appears to be leaning toward the establishment of a non-military system for satellite signals or at least to combine signals from GPS and GLONASS. The European Union is not likely to pursue a GPS-based option for its signal source for precision approaches for two reasons.

First, the European alliance does not want to be beholden to U.S. political and military interests. Although the recent history of Desert Storm and the world-wide coalition reflected indicated a close military and political relationship where the major partners shared common goals, this has not always been the case. One only has to look at

the 1980s where American military actions caused division among its European allies. The military operations in Panama in 1989, Libya in 1986, Granada in 1983 are three examples where European support was far from strong and unanimous. The Vietnam War also drew substantial criticism from European circles. The memory of these events is a significant reason for European caution to become reliant on the DOD system for their navigation and approach infrastructure.

The second reason is that the timing of the advent of the satellite-based system coincides with the rise of the European Union. This new coalition, with the collective resources of a military and economic superpower also gives rise to a new sense of European pride with the recognition of the capability and means to emerge from the American technological shadow. This European Union will not be eager to place itself at the mercy of another superpower nation for the availability of satellite navigation signals.

DOD Plans

The DOD is proceeding quickly, though not recklessly, in its plan to equip its aircraft with the avionics necessary to function in the 21st century environment. Beginning with enroute navigation with future plans for precision approach capability, the GATM concept is in place to assure that DOD aircraft are well equipped to be fully functioning members of the air traffic system.

Due to the likelihood that the Europeans will develop a system that incorporates signals from more than one source including, perhaps, its own civil satellite system, it is likely that they would require the use of these various signal sources to function in their airspace. Therefore, the DOD might want to consider equipping its aircraft with the

capability to interrogate signals from multiple sources, not just GPS. Although there are definitely certain DOD security concerns to this approach, the ability to interrogate multiple type signals within the European theater would not hinder the U.S. ability to deny signals to potential enemies in the forward-deployed environment.

There are a number of advantages to this strategy. First of all, it adds to the number of signal sources. As mentioned in this paper, research indicates that accuracy improves when signals from an increased number of satellites are interrogated. Second, increasing the number of satellites from which to obtain signals would add redundancy to the system and insulate it from the effects of failure from a single satellite. Third, the coverage would increase leading to virtually no gaps in coverage. Because the DOD is already considering increasing its GPS constellation to 30 functioning satellites, the wisdom of a larger constellation appears to have already been accepted. Increasing the constellation by simply utilizing other non-American sources would be less costly and also demonstrate American commitment to a truly international system where it could still play a leading role.

Backup System

Because the same satellite system could provide signals for high-level enroute navigation as well as for precision approach, there is concern that there will be a single point of catastrophic system-wide failure. There is some concern among experts of adequate backup systems to satellite-based precision approaches. A network of Loran signals, traditional VOR-DME systems and precision approach radar and ILS approaches should be maintained at many locations in the event of failure. As the satellite systems

improve and bring in new concepts that are merely in the conceptual stage today, the need for traditional backup systems may be reduced.

APPENDIX A

ABOUT GPS

The GPS system is a satellite-based radio navigation, positioning and time transfer system funded and controlled by the U.S. Department of Defense (DOD). Estimates place the original cost of deploying the system at $10 billion. While there are thousands of civil users of GPS world-wide, the system was designed and operated by the U.S. military. GPS was designed and deployed with the original purpose of providing U.S. military forces with accurate positioning signals in air, sea and land operations when alternative sources of information might not be reliable or readily available.

GPS consists of three major segments: space, control and user. The space segment is the 24 orbiting satellites. Navigational signals are sent from these vehicles. They are deployed in six orbital planes spaced 60 degrees apart. Each of these planes contains four satellites. Orbiting at approximately 10,800 miles above the earth these satellites orbit the earth every 12 hours. The control segment consists of tracking stations located around the world. The control segment includes a master control station, five monitor stations and three ground antennas. The Master Control Station is located at Falcon Air Force Base in Colorado Springs Colorado. The monitor stations are located at the Master Control Station, Hawaii, Kwajalein, Diego Garcia, and Ascension Island. The user segment consists of the GPS receivers and associated equipment. The GPS receivers, using data transmitted by the satellites, derive position, navigation, and time information and display the appropriate data to the individual GPS users.

The GPS signals are transmitted on two frequencies. The L1 frequency (1575.42 MHz) carries the navigation message and the Standard Positioning System (SPS) signals. The L2 frequency (1227.60) is used to measure the ionospheric delay for Precise Positioning System (PPS) which was intended solely for military users. The SPS signals are intentionally degraded by the DOD by the use of Selective Availability. The U.S. has announced that it will end this practice by 2006. This would provide positioning signals to all users with an unaugmented accuracy of approximately 10 meters when a sufficient number of satellites are properly interrogated (Dana, 1997).

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Vita

Major Timothy J. Quinn was born on 20 October 1959, in Fort Bragg, North Carolina. He graduated from Michigan State University in 1981 with a Bachelor of General Business Administration. Prior to joining the Air Force, he worked in Michigan as a retail manager with the Muir Drug Company. Following Officer's Training School in 1984, he completed Undergraduate Navigator Training at Mather AFB, California.

His first operational assignment was at K.I. Sawyer AFB, Michigan where he served as KC-135 navigator, instructor navigator and the chief evaluator navigator for the 307th Air Refueling Squadron. Major Quinn became a CCTS Instructor Navigator in 1990 at Castle AFB, California. He also served as Chief, KC-135 Navigator Curriculum Development, and as CFIC Chief of Training. He then served as MAJCOM Aeronautical Route Planning Director at the Tanker Airlift Control Center at Scott AFB, Illinois where he was later selected as the Curriculum Development Chief for the Inspector General Training Branch at AMC.

In May 1997, Major Quinn was assigned to the Air Mobility Warfare Center as a student in the Advanced Study of Air Mobility (ASAM) program. After graduation, he will assume duties in the Mobility Operations Branch, Air Mobility Warfare Center.

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13. ABSTRACT *(Maximum 200 words)*

The tremendous growth in the amount of worldwide air traffic has also brought increasing congestion in the skies. Air Traffic Control agencies are attempting to shape policies to alleviate air traffic volume problems in terminal areas using new satellite technologies.

This paper examines the current and future regulatory and policy environment for the use of satellites, particularly the Global Positioning System (GPS), as a stand-alone method of precision approaches from three perspectives: the Continental United States (CONUS), the European continent, and the Department of Defense (DOD). Each of these perspectives presents unique obstacles in the adoption of satellites as the sole use for precision approaches.

Finally, three conclusions are offered regarding the transition to satellites for the precision approach system of the 21st century. First, a truly single source global satellite system (e.g. GPS) probably may never exist, but rather, there will be a combination from various governments and agencies. Second, satellite users should consider using systems capable of interrogating signals from more than one satellite source. Finally, air traffic control agencies should maintain a network of backup precision approach systems until the success of a stand-alone satellite system is established.

14. SUBJECT TERMS
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